Ocean Acoustics and Signal Processing for Robust Detection and Estimation

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LONG TERM GOALS

The long-term goal of this project is to develop methods for geoacoustic inversion, localization, and detection by combining the physics of sound propagation in the ocean and principles of signal processing.

OBJECTIVES

1. Develop matched-field inversion methods (with known source spectrum), using both the spatial and temporal structure of the acoustic field for more robust inversion performance.
2. Develop efficient and accurate search methods for passive and active matched-field inversion through searches in small parameter (sub)spaces; search space selection is based on the sensitivity of the acoustic field to different parameters and correlation patterns between parameters.
3. Develop detectors and source location estimators for shallow water environments that circumvent the exhaustive replica computation required by the optimal model-based matched-filter without compromising performance.

APPROACH

Data are available from part of the SWellEX 96 experiment where the source transmitted lfm and hfm pulses. In order to invert for geometry and the environment, and since the source spectrum is known, time-series correlation between measured data and replicas was implemented. This approach to matched-field inversion proved to be very successful but very computationally demanding. To take advantage of the time-series matching without the large computational overhead, an alternative was explored: the impulse response of the medium was extracted from the received data and was then correlated to replica impulse responses. Impulse response extraction operates as a way of data compression, mapping the received time-series to much shorter sequences. This procedure leads to a small performance degradation from the full time-series matching, but appears to be a powerful inversion tool, preferable to conventional, incoherent, broadband matched-field methods.

The search for the maximum of the inversion objective functions was performed in a hierarchical fashion, layering the search space in low-dimension subspaces. The initial stage of the search was performed in the water column depth, source range, and source depth subspace, since those parameters appeared to be critical for high correlations between received and replica fields. The search included

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sediment properties in a second stage. Results of the second stage were then used to obtain more refined estimates for the first parameter group.

Optimization methods, genetic algorithms and simulated annealing variants, were also implemented and tested for geoacoustic inversion and localization (in collaboration with Dr. Peter Gerstoft). Experiments with both synthetic and real data were designed to assess the performance of different optimization techniques in matched-field inversion. The experiments explored the potential of the optimization techniques for accurate and fast estimation and the correlation between the quality of the estimates and the method employed for the exploration of the search space.

Active time-domain matched field processing is also being pursued. For detection, a new processing scheme was implemented making a detection decision on the basis of the N largest peaks of the source-receiver correlator output (N is a parameter selected based on the expected number of multipaths at the receiver; N does not need to be known exactly). The method is very similar in concept to the replica-correlation-integration approach [1, 2] but is simpler in implementation.

RESULTS

Geoacoustic inversion with impulse response matching was compared to a standard incoherent combination of Bartlett surfaces and a coherent variant of the Bartlett processor [3]. The comparison showed that the impulse response matching technique gives less uncertain estimates of geoacoustic and geometry parameters than incoherent Bartlett averaging without a significant increase in the computational requirements. Inversion was initially performed with near range data; results of the inversion process were then used to localize the source from longer range data. Range independent modeling was used for the replica generation although the environment underwent bathymetric changes between source and the receiver at the long range case. The impulse response matching localization results were significantly better than the incoherent location estimates indicating the robustness of the method to environmental mismatch [4].

The optimization experiments demonstrated that the search method is critical for successful inversion. Most optimization techniques that were studied lead to fast and accurate inversion. However, the convergence rate depended heavily on how the parameter space was explored. Allowing moves in any direction in the parameter space generally enhanced the performance of all techniques [5].

For active detection, the modified matched-filter accounting for the expected number of multipaths at the receiver improved the performance of the simple, suboptimal source-receiver matched filter, but, as expected, was inferior to active matched-field processing (or model-based matched-filter) for a perfectly known environment [6].

IMPACT

Matched-field inversion based on impulse response estimation from received data at spatially separated hydrophones accounts for both the temporal and spatial coherence of the acoustic field incorporating more information than standard frequency domain matched-field processing, producing more reliable estimates of the unknown parameters. The gain in performance comes with only a slight increase in computational requirements. Also, the optimization results indicate how parameter searches should be performed for higher efficiency and accuracy. Improvement in geoacoustic inversion will enhance greatly underwater detection and localization.

The active domain matched-filtering technique is simple, exploiting knowledge that the received field is a superposition of the transmitted signal replicas because of waveguide effects. The detector is robust with respect to mismatch in the assumptions for the propagation medium. Results show that it is possible to improve underwater target detection in shallow water without involving extensive computation.

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